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The Development of Initial Asphalt Mixture Acceptance Criteria Using the SCB test and the I-FIT Test

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The Development of Initial Asphalt Mixture Acceptance Criteria
Using the SCB test and the I-FIT Test

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Abstract

Cracking has become the primary asphalt pavement distress in Arkansas. Arkansas along with other states have implemented a test to measure rutting resistance. This paper presents research to implement a cracking resistance test to further modify the Superpave volumetric asphalt mixture design method in Arkansas. The Illinois Flexibility Index Test (I-FIT) was the test chosen to analyze for this research. Two aging methods were tested, a short term oven aging (AASHTO R30 ST) and a long term oven aging (NCAT) method. Six asphalt mixtures were selected to be tested. The mixtures testes were recreated from Arkansas Department of Transportation (ARDOT) projects that had been paved and distress surveys completed on. The mixtures fell into three categories, Poor, Fair, and Good cracking performance. After testing in the lab, the Flexibility Index (FI) values statistically grouped into three groups. The results showed that higher FI values had higher variability. Using the results from this research, recommendations are made to Arkansas on a minimum FI value to be used for acceptance and which aging protocol to use.

Acknowledgments

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DEDICATION

This thesis is dedicated to my Lord and Savior Jesus Christ. Jesus is Lord!

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Introduction

Arkansas currently uses a “modified” Superpave asphalt concrete (AC) mixture design procedure. The Superpave procedure resulted from research made possible by legislation passed in 1987 by the United States Congress. This funding provided $150 million dollars to the Strategic Highway Research Program (SHRP) and one third of that funding was used to create a performance-based asphalt design specification to relate laboratory analysis directly to field performance (Goad, 1998).

The Superpave procedure as stated was intended to be a performance-based asphalt mixture design. However, due to the expense of equipment, states did not adopt the performance testing aspect of the design procedure. This in effect made the Superpave procedure a volumetric design procedure. Although Superpave is a volumetric design, there has been a push in industry to modify Superpave by adding performance tests to create more performance-based asphalt mixtures.

Arkansas, along with many other states, has already implemented a performance test to analyze rutting resistance of asphalt pavements. The Arkansas Department of Transportation, ARDOT, has implemented a test for determining rutting susceptibility using a Loaded Wheel Tester (LWT), (ARDOT Test Method 480-07.) Currently however, the state has not yet implemented a test to analyze cracking resistance of asphalt pavements.

The Semi-Circular Bending Test (SCB) and Illinois Flexibility Index Test (I-FIT) have been investigated as potential tests to implement in Arkansas to analyze cracking resistance during the mixture design process of asphalt pavements. I-FIT is a product of the Illinois Center for Transportation (ICT) and Illinois Department of Transportation (IDOT). I-FIT was developed as a method and protocol that can rank AC mixtures based on their cracking resistance (Al-Qadi et al. 2015).

This paper discusses research conducted to evaluate the potential of the SCB and I-FIT tests to analyze the cracking resistance of AC mixtures in the state of Arkansas. The method of testing and results obtained will be discussed along with a recommendation to the ARDOT regarding the suitability of I-FIT. Implementation of a cracking test would allow for the Arkansas to move more towards performance-based AC mixture design. This may increase the life of AC pavements, decreasing the cost of maintenance and upkeep of roads in the state. Research for this project was conducted at the Department of Civil Engineering at the University of Arkansas in Fayetteville. The research was conducted under project TRC 1802 which was sponsored by ARDOT.

Background

During the 1998 calendar year Arkansas implemented Superpave to replace the Marshall Method which had been created in 1939 by Bruce Marshall (Goad, 1998). The Superpave volumetric design process in Arkansas follows AASHTO M 323 and AASHTO R35. This design system is based on component specifications (quality and properties of the asphalt binder and aggregates) and volumetric properties (Hall et. al. 2017). This method has binder performance grade requirements that must meet AASHTO M 320 and aggregate gradation requirements, where a gradation must pass through set control points dependent on the Nominal Maximum Aggregate size in the mix. This method also has volumetric properties that must be met including, Voids in Mineral Aggregate (VMA) and Voids Filled with Asphalt (VFA).

Volumetric properties only indirectly control the engineering properties of asphalt mixtures. When Superpave was developed it was intended to include performance-based tests – that is, tests that measure engineering properties directly related to performance. However, the original performance-based tests were never implemented by DOT's due to the expense of equipment developed. The use of performance-related tests, along with the volumetric design, provides a performance-based mix design or "balanced" mix design. In 2015, the FHWA Expert Task Group on Asphalt Mixtures and Construction formed a Task Force on Balanced Mixture Design. This task group defined balanced mixture design as "Asphalt mixture design using performance tests on appropriately conditioned specimens that address multiple modes of distress taking into consideration mixture aging, traffic, climate, and location within the pavement structure."

The goal of balanced mix design is to adjust the material proportions and properties of a given mixture based on the results of performance testing. Figure 1 provides an illustration of how mixtures would be adjusted. As binder content increases rutting resistance decreases while cracking resistance increases, and vice versa. The goal of balanced mixture design is to find a range of binder content where rutting resistance and cracking resistance are balanced. Today balanced asphalt mixture design has three possible faces. They are as follows: 1. Volumetric Design with Performance Verification; 2. Performance-Modified Volumetric Design; and 3. Performance Design. Figure 2 is a flowchart that outlines these three methods.

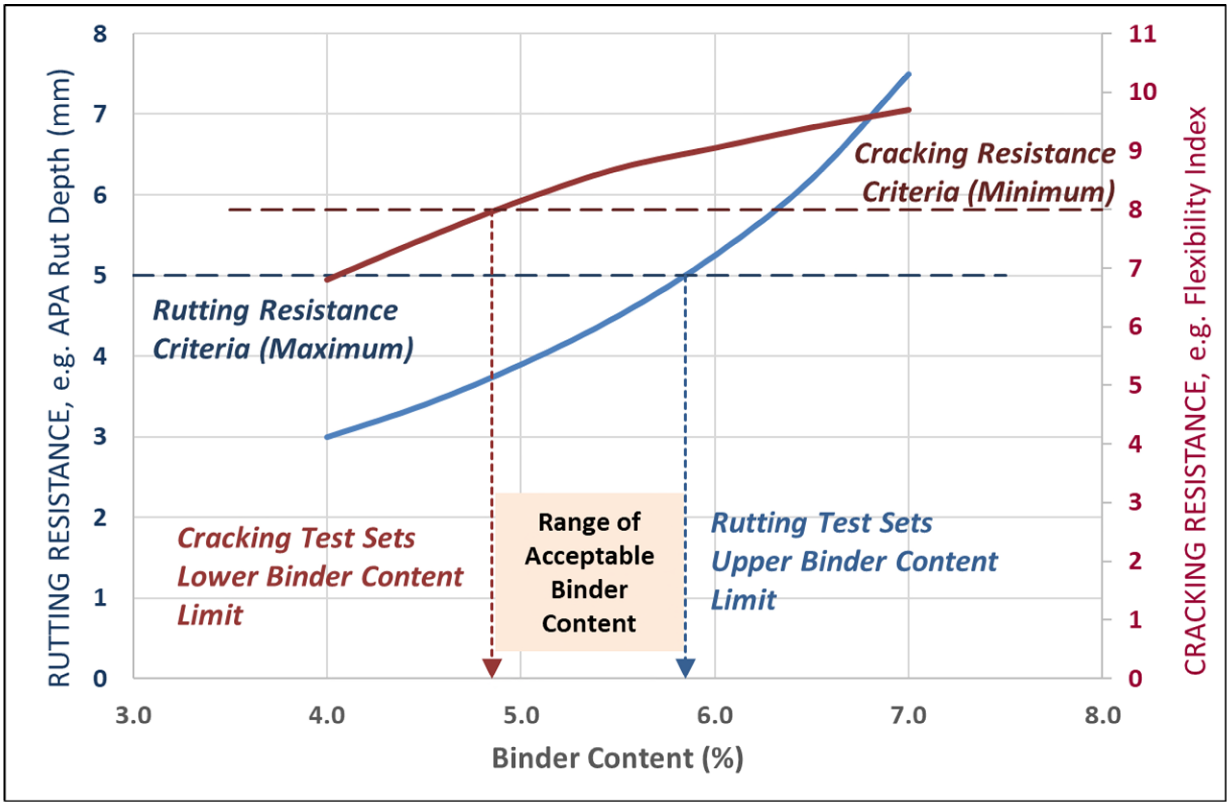


Figure 1. Performance Mix Design (Hall et al. 2017)

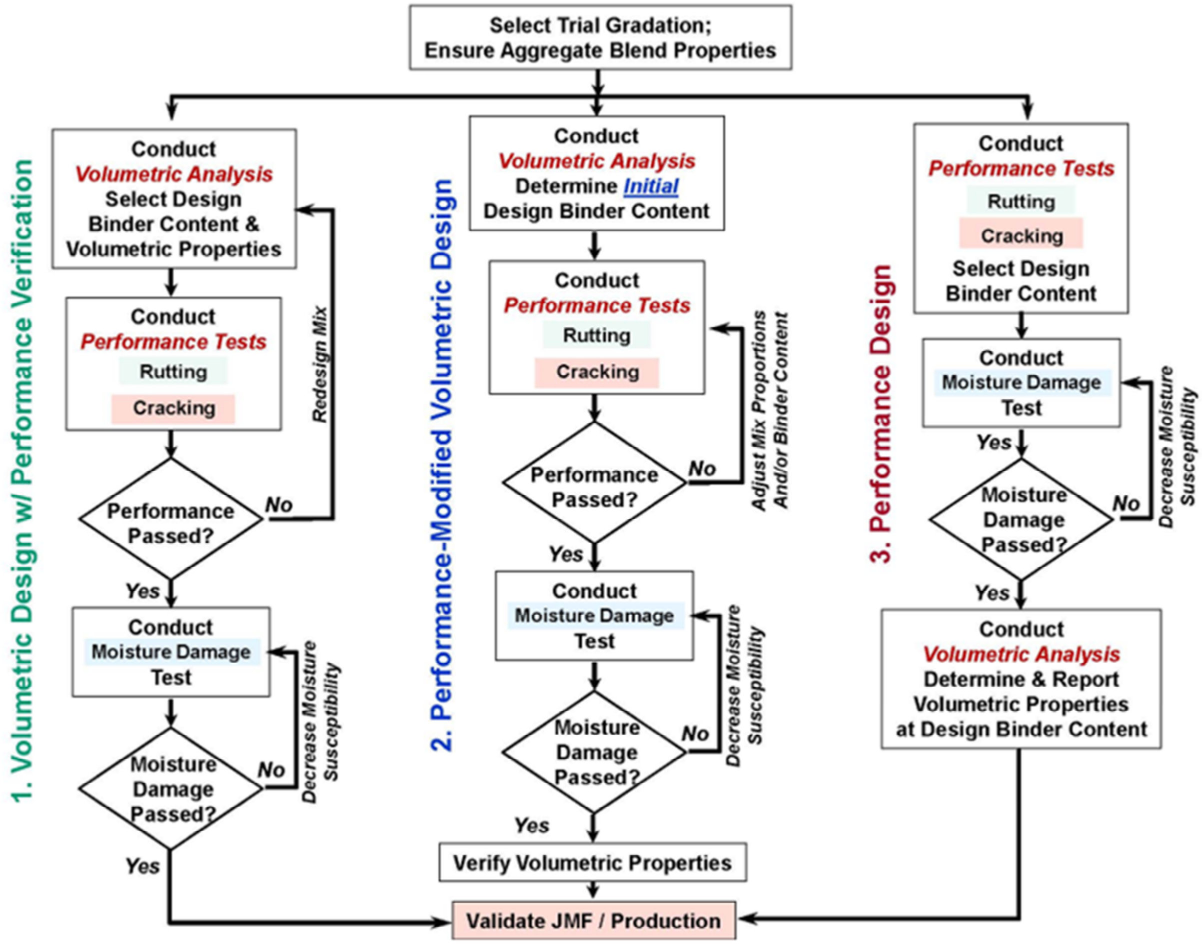


Figure 2. Methods of Performance-Based Asphalt Mixture Design (Hall et al. 2017)

The first of the three faces is Volumetric Design with Performance Verification. Mixes are designed using volumetric properties, and performance properties are subsequently confirmed in this method. Both volumetric and performance test results must meet established criteria. If performance properties require adjustment, a new design is executed. This is the most common approach currently in use by state highway agencies (Hall et al. 2017). The second of the faces is Performance-modified Volumetric Design. This method includes volumetric design as a preliminary step. Volumetric design is used to determine an initial binder content and performance tests are conducted at that binder content. Mixture proportions are adjusted based on the results of the performance tests. Mixes designed using this method may be required to meet minimum volumetric requirements or none at all. The third method shown in Figure 2 is Performance design. Mixture design for this method is based solely on performance properties. There are no volumetric limitations placed on the mixture and a volumetric analysis is only completed once a mixture design meets the performance criteria.

The ARDOT already modifies the volumetric Superpave approach with a performance test. Arkansas has implemented a test for determining rutting susceptibility using the Asphalt Pavement Analyzer (APA). With the addition of a cracking resistance test, asphalt mixture design would continue to move towards a true performance-based asphalt mixture design, where performance properties are directly measured, rather than a performance-related mixture design where volumetric properties are indirectly related to performance properties.

The SCB and I-FIT tests are one method of analyzing AC pavement cracking resistance. Other methods of analyzing AC pavement cracking can be seen in Table 1. The I-FIT protocol was developed by ICT and IDOT (Al-Qadi et al. 2015). The SCB test is the physical test where a semicircular specimen is tested using a SCB fixture placed in a servo-hydraulic or pneumatic AC testing machine (AASHTO TP 124). A line load is placed on the sample at 50 mm/min until failure occurs. Figure 3 is an example of a specimen being tested as well as SCB specimen dimensions. The testing is conducted at an intermediate temperature of 25ºC (77ºF). For this test specimens are either compacted to a height of 160 mm using a SGC or can be collected from the field as cores (AASHTO TP 124). Once the specimens are obtained, they are cut into two 50 mm disks which are to have 7 percent air voids. These disks are cut in half to form two semi circles, and a notch is cut into the center of each semi circle.

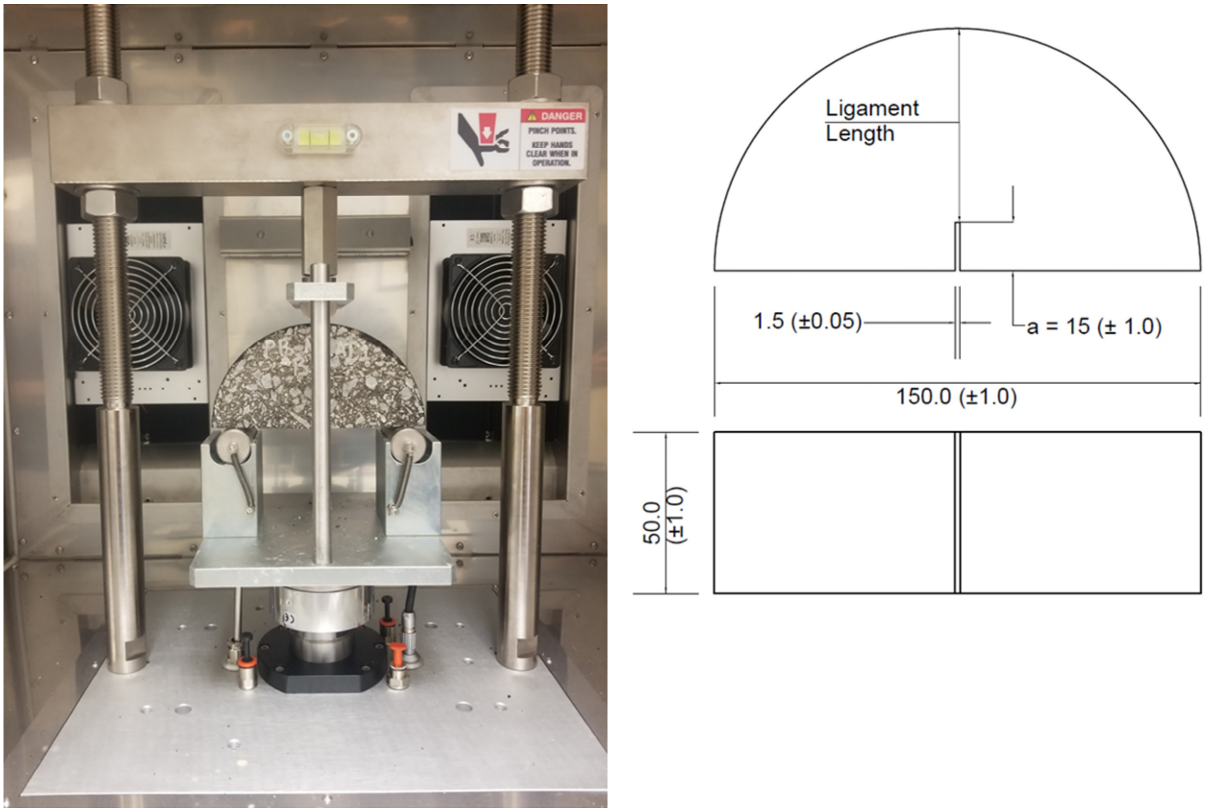


Figure 3. SCB and I-FIT Test

I-FIT is a method of analyzing of data collected during the SCB test. The I-FIT protocol was developed to evaluate an asphalt mixture's overall resistance to cracking-related damage (Al-Qadi et al. 2015; Ozer et al. 2016a; Braham et al. 2016). The test was intended to be used at the mix design and production levels (Braham et al. 2016). If deemed an acceptable test for Arkansas it would be used in that capacity. The main result of I-FIT is a Flexibility Index (FI). This index is a function of fracture energy (G_{fa}) reported as joules/m^2 and the absolute value of the post-peak slope at the inflection point (|m|) reported as kN/mm. The variable (A) in the equation below is a unit conversion factor and scaling coefficient (Ozer et al. 2018).

$$\mathrm{FI} = \frac{G_{fa}}{|m|} x\ A \qquad (1)$$

According to the work-of-fracture method (Hillerborg, 1985: Bazzant, 1996), fracture energy is the area under the load-displacement curve until the specimen is broken. Figure 4 is an example of the load displacement curve created. The area corresponds to the work done by load (P) on the load-point deflection (u). Assuming that all of the work of the load P is dissipated by the crack formation and propagation, this work would correspond to fracture energy. The method determines fracture energy, or more accurately, apparent fracture energy, because not all energy may be dissipated at the crack tip, as follows:

$$G_{fa} = \frac{1}{b(D-a)}\left[\int_0^{u_0} P_1(u)du + \int_{u_o}^{u_{final}} P_2(u)du\right] \quad (2)$$

Where $P_1(u)$ and $P_2(u)$ are the fitting equations before and after the peak, respectively; u_0 = displacement at the peak; and u_{final} = final displacement that can be selected as the displacement at a cut-off load value where the test is considered at an end (usually taken as 0.1 kN). If desired, the load-displacement curve can also be extrapolated to calculate the remaining area under the tail part of the curve, which is generally less than 5% of the total area. (Ozer et al. 2018)

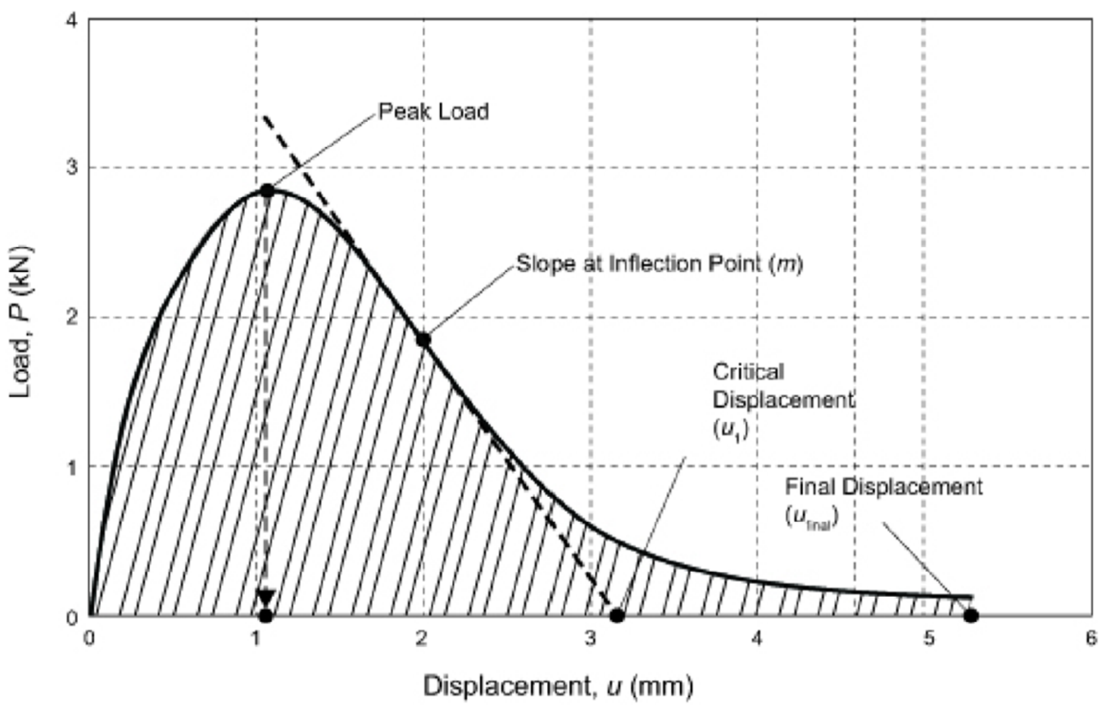


Figure 4. I-FIT Load Displacement Curve

Project Objective

Nationally, there is a concern that asphalt pavements are experiencing premature distress and failure (Hall et al. 2017). A survey was conducted as part of NCHRP Synthesis 492 “Performance Specifications for Asphalt Mixtures” (McCarthy et al., 2016) that indicated a concern among state highway agencies that current asphalt mixture design procedures do not ensure good field performance. The state of Arkansas shares that concern. As stated previously the state of Arkansas has already begun to modify the volumetric Superpave design procedure with a loaded wheel tracking test to indicate rutting susceptibility. It is the objective of this research to analyze a test method that characterizes cracking resistance of asphalt mixtures for Arkansas. The focus of the project is load related cracking; that is, reflection cracking, bottom-up fatigue, and top-down cracking (Hall et al. 2017). Table 1 summarizes the findings from Zhou, et. al. (2016) for load related cracking.

Table 1. Cracking Parameters and Field Performance Correlations for Cracking Tests (after Zhou et. al. [2016])

Test Name	Cracking Type	Cracking Parameter	Correlation to Field Performance
SCB-LTRC	Bottum-up fatigue Top-down	Energy Release Rate	Fair correlation from Louisiana pavement management system
SCB-IL	Bottum-up fatigue Top-down	Flexibility Index (FI) *(related to fracture energy)*	Ongoing Validation work in Illinois
OT	Reflection: Bottom-up fatigue	No. of cycles, or fracture parameters	Good correlation with reflection cracking validated in TX, CA, NJ; Promising correlation with fatigue validated FHWA-ALF and NCAT test track
BBF	Bottum-up fatigue	No. of cycles, or fatigue equation	Correlation with bottom-up fatigue historically validated
IDT-Florida	Top-down	Energy Ratio	Validated with field cores in Florida; confirmed at NCAT test track

OT: Texas Overalay Test
SCB: Semi Circular Bend Test
IDT: Indirect Tension Test
FHWA: Federal Highway Administration
ALF: Accelerated Load Facility
BBF: Bending Beam Fatigue Test
LTRC: Louisiana Transportation Research Center
IL: Illinois
NCAT: National Center for Asphalt Technology

SCB-IL or I-FIT was selected from Table 1 as the cracking test to be analyzed for this project. I-FIT was selected to be analyzed for implementation in the state of Arkansas primarily for its ease of implementation (it may be possible for the state to use equipment they already have to perform the tests). This research hopes to show that the I-FIT is able to discriminate between ductile and brittle mixture, (a ductile AC mixture deform under load before failure where a brittle AC mixture will not deform before failure under load) therefore demonstrating that it is able to discriminate mixture performance.

Materials and Methods

Site Selection

ARDOT maintains a database compiling field performance data as part of its "Next 25" program. Though it is identified as having 25 projects, the database is a compilation of 40 sites across the state, including 32 asphalt pavements and 8 concrete pavements. The primary data considered from the Next 25 program was the field distress surveys. The surveys are a series of ten grids, each grid containing a total area of 850 square feet (Richey, 2017). A total of 121 field data surveys were evaluated for site selection. Once evaluated, the sites were ranked from least cracking to most longitudinal cracking present. Longitudinal cracking is typically top down and can generally be assumed to be a metric of cracking due to loading that is not structural failure. These rankings were further divided into three categories; Poor, Fair, and Good. Figure 5 shows the sites and their breakdown. The criteria for determining the categories represents statistical 'breaks' in the data (Richey, 2017).

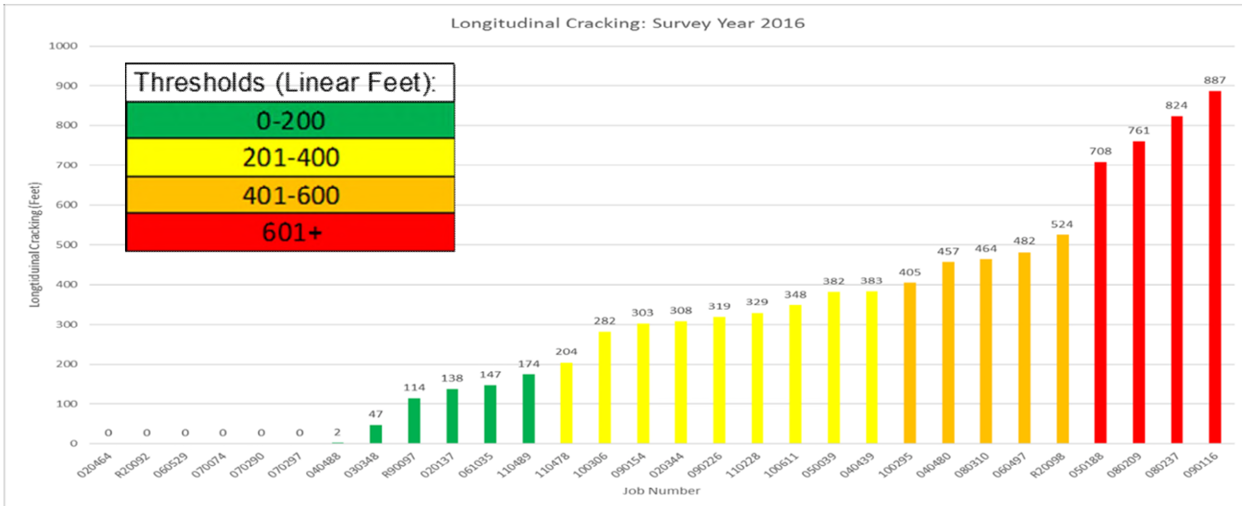


Figure 5. Site selection rankings

Sites labeled red were ranked as poor, sites the color yellow are ranked fair, and sites the color green are ranked as good performing. Two sites from each ranking were chosen to re-create their asphalt mixture designs. The sites from the poor rating include Hindsville and Judsonia, the fair rating include Jonesboro and Heber Springs, and the good rating include Pine Bluff and DeQueen. The names correspond to the city closest to where the road was paved. Figure 6 is a state map that shows the location of the sites selected. While selecting the six sites an attempt was made to choose sites within each ranking that had similar truck traffic and daily traffic so that a more accurate comparison could be made.

Figure 6. Site Selection Map (Google Earth)

Mixtures

ARDOT provided the original Job Mix Formulas (JMF) for the sites selected to test. The JMF provided asphalt mixture designs for all courses (Base, Binder, and Surface). However, only the 12.5 mm surface course is being considered in this study, as this is the layer of AC pavement that top down longitudinal top down cracking will take place in. It can be seen in the site selection map that the mixtures come from different areas of the state. Trips were made to the quarries or asphalt plants used in the production of asphalt for each site. Each mix design was composed of five different aggregates. Approximately 80 five-gallon buckets of aggregate were obtained from each location. The aggregate was sampled from the bottom of the pile. Therefore, to ensure proper gradation the aggregate was fractionated over select sieves. The sieve sizes were determined based on the aggregate gradation listed in the original JMF. Once fractionated, the aggregates were blended to form a gradation equal to the JMF.

It was noted that the aggregate obtained would have been from a different part of the quarry (the roads selected were paved as long as 10 years ago) and that the rock may not have the same properties as the aggregate originally used. Thus, aggregate specific gravities were conducted on the rock in accordance to AASHTO T 84 and AASHTO T 85 once the aggregates were blended. Specific gravity data indicated the aggregate to be similar to the properties shown in the original mix design (typically within 5% of the JMF value) .

Once the aggregates were blended the mixture design continued. The aggregate and binder was heated to mixing temperature, mixed in a bucket mixer, and then placed in an oven at the compaction temperature for the 2 hour short term oven aging (STOA) according to AASHTO R 30. Binder, mixing temperature, and compaction temperature were all site specific. The sites selected either used an unmodified PG 64-22 or polymer modified PG 70-22 binder. It is to be noted that the binder used for this research was donated from a single source, rather than attempting to obtain binder from the supplier of each specific mixture placed in the field. After the STOA the asphalt mixture was either compacted using a Superpave Gyratory Compactor (SGC) at the design gyration level (N_{design}) listed in the JMF (100 gyrations for the PG 70-22 and 75 gyrations for 64-22) or cooled in an uncompacted state for subsequent testing of maximum specific gravity (G_{mm}). A bulk specific gravity (G_{mb}) test was conducted on the compacted specimens in accordance with AASHTO T 331 and G_{mm} tests were conducted according to AASHTO T 209. The values obtained were used to calculate the values of percent air voids and VMA of the asphalt mixtures. The calculated values were then compared to the values in the JMF. If the values did not closely match the gradation and binder content of the asphalt mixture was adjusted slightly until the volumetric properties for the lab created mix were similar to the values given in the JMF. Table one is a comparison of the percent air voids and VMA of the JMF compared to what was recreated in the lab.

Table 2. Volumetric properties

		JMF	Recreated Mixture
Hindsville	Percent Air Voids	4.5	4.54
	VMA	14.8	14.91
Judsonia	Percent Air Voids	4.5	4.7
	VMA	14.8	15.03
Jonesboro	Percent Air Voids	4.5	4.8
	VMA	14.4	14.22
Heber Springs	Percent Air Voids	4.5	4
	VMA	14.9	14.47
Pine Bluff	Percent Air Voids	4.5	4.9
	VMA	14.7	14.76
DeQueen	Percent Air Voids	4.5	4.5
	VMA	15.8	14.83

The verified mixture designs were then used to create performance specimens. After mixing the performance specimens, AASHTO R 30 STOA and National Center for Asphalt Technology (NCAT) long term oven aging procedures were used. Table 3 is a summary of the two aging protocols.

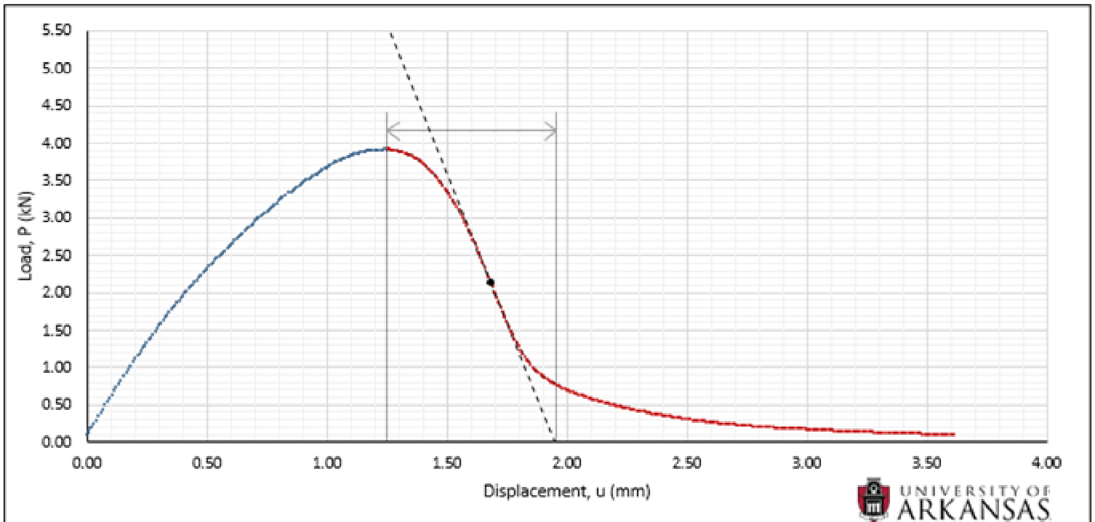
Table 3. Aging Protocol Comparison

	AASHTO R30 ST	**NCAT**
Temperature:	Compaction Temp	135°C
Aging Time:	2 hours	8 hrs
Stir Time:	once per hour	once per hour

These aging protocols were chosen out of convenience of use in the lab (Hall et al. 2019). The STOA consisted of 2 hours at the compaction temperature while the NCAT long term oven aging protocol required 8 hours at 135ºC. It was decided to make 3 gyratory pills for each aging protocol, each pill producing 4 semi-circle specimens, based on statistical analysis to determine how many replicas were needed to make the study relevant. At the conclusion of the aging periods the performance specimens were compacted to a height of 160 mm and approximately 7.75 percent air voids using a SGC. The specimens were then cut into two 50 mm disks. 20 mm was cut off each end of the disk and the remaining 100 mm specimen was then cut in half. This method was used to achieve a more even distribution of compaction and air voids in the specimen being tested. The inner portion of the 160 mm specimen as previously mentioned will have slightly different properties. Each disk was to have 7 ± 0.5 percent air voids in accordance with AASHTO TP 124. The total air voids for the 160 mm specimen is higher than the 50mm disks and this is why 7.75 percent air voids was targeted. The corelok method to determine Gmb (AASHTO T 331) was used for validation. After air voids had been measured, the disks were then cut into two identical halves with dimensions detailed in Figure 3. The semi-circle halves were then measured using a digital caliper to ensure the tolerances shown in the figure were met. The specimens were then immersed in a water bath at 25ºC in accordance with AASHTO TP 124. Following the water bath, the specimens were tested. The specimens were placed in a custom SCB fixture and a line load of 50 mm/min was induced until failure of the specimen. Displacement and load data were collected during the duration of the test from which a load displacement curve could be created.

Results and Discussion

I-FIT testing was conducted on each Arkansas site that was selected. Long term and short-term aging protocols were applied for each site. Load displacement curves were created for every specimen tested and Figures 7 and 8 are examples of these load curves.



RESULTS		
Peak Load =	3.9160	kN
Displacement at = Peak Load (u_0)	1.2405	mm
Work of Fracture (W_f) =	5.4047	J
Ligament Area ($Area_{lig}$) =	0.0030	m^2
Fracture Energy (G_f) =	1830.3	J/m^2
Post-peak slope (m) =	-7.99	kN/mm
Critical Displacement (u_1) =	1.9486	mm
Flexibility Index (FI) =	**2.29**	

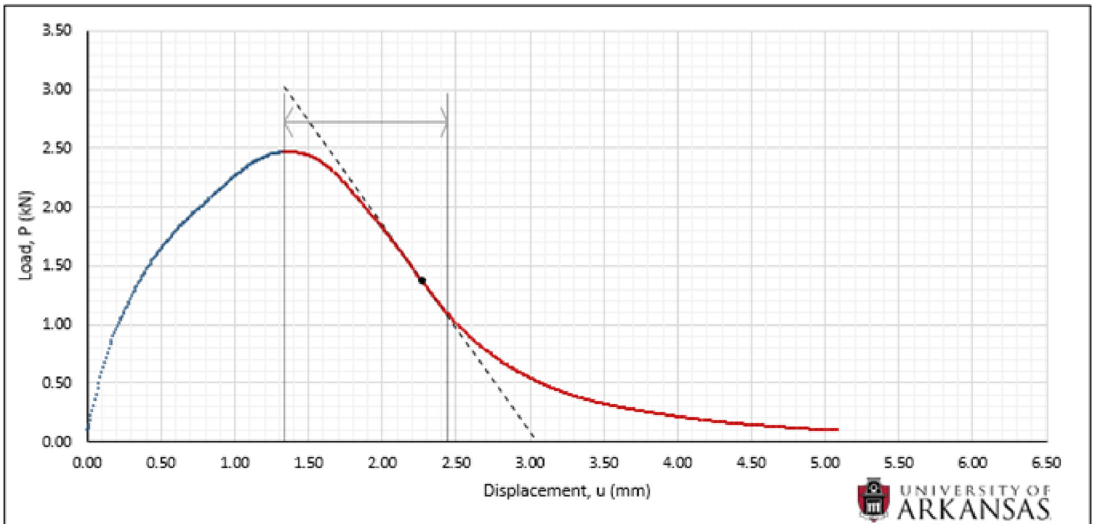
SPECIMEN DIMENSIONS		
Radius (r) =	73.70	mm
Notch Length (a) =	15.10	mm
Thickness (t) =	50.39	mm

ILLINOIS FLEXIBILITY INDEX TEST (I-FIT)
UNIVERSITY OF ARKANSAS
Laboratory of Pavements and Materials

Test Date:	Wednesday, October 24, 2018
Project ID:	TRC 1802
Specimen ID:	Heber Springs NCAT
Technician:	N Parnell

File Name: UARK_SCB-IFIT_v9.4 HS_NCAT1_T1.xlsm

Figure 7. Example of NCAT aging protocol load displacement curve



RESULTS		
Peak Load =	2.4725	kN
Displacement at = Peak Load (u_0)	1.3252	mm
Work of Fracture (W_f) =	5.3876	J
Ligament Area ($Area_{lig}$) =	0.0029	m^2
Fracture Energy (G_f) =	1831.1	J/m^2
Post-peak slope (m) =	-1.77	kN/mm
Critical Displacement (u_1) =	3.0439	mm
Flexibility Index (FI) =	**10.37**	

SPECIMEN DIMENSIONS		
Radius (r) =	74.04	mm
Notch Length (a) =	15.17	mm
Thickness (t) =	49.98	mm

ILLINOIS FLEXIBILITY INDEX TEST (I-FIT)
UNIVERSITY OF ARKANSAS
Laboratory of Pavements and Materials

Test Date: Wednesday, October 24, 2018
Project ID: TRC 1802
Specimen ID: Heber Springs R30 ST
Technician: N Parnell
File Name: UARK_SCB-IFIT_v9.4 HS_R30ST1_T1.xlsm

Figure 8. Example of R30 ST aging protocol load displacement curve

Figure 7 is a Heber Springs long term oven aging specimen and Figure 8 is a Heber Springs short term oven aging specimen. It can be noted by looking at Figure 7 and Figure 8 that though fracture energy may be similar, the FI's can be vastly different. The fracture energy of the two specimens differs by less than 1 J/m^2. However, the FI indices differ by 10. This is due to post-peak slope. The steeper slope (Figure 7) produced the lower the flexibility index. The steeper slope indicates a brittle mixture that failed immediately after peak load was achieved.

Table 2 is a list FI averages for each site and aging protocol. As expected, the long-term oven aging specimens had a lower FI for all sites tested. This is due to the time spent in the oven; the longer the asphalt mixture spends in the oven the "stiffer" (or more brittle) the mixture becomes. A stiffer or more brittle mixture will have a higher susceptibility of cracking. The lower FI of the long-term oven aging specimens validate that statement

Table 4. Flexibility Index Averages

	Short Term Aging	Long Term Aging
Hindsville	3.96	1.38
Judsonia	4.66	0.94
Jonesboro	8.48	3.11
Heber Springs	10.55	2.49
Pine Bluff	2.61	0.64
DeQueen	2.14	0.57

Figure 9 is a graph detailing the data presented in Table 2. The poor and fair sites seem to follow a correlating trend to the field performances. The poor performing field sites also had poor performing laboratory results, shown in low FI values. As hoped, the fair performing field sites had higher FI values than the poor sites. This trend, however, ended with the fair performing sites. As seen in Figure 9, the good performing sites had lower FI values for both aging protocols than both the fair and poor performing sites.

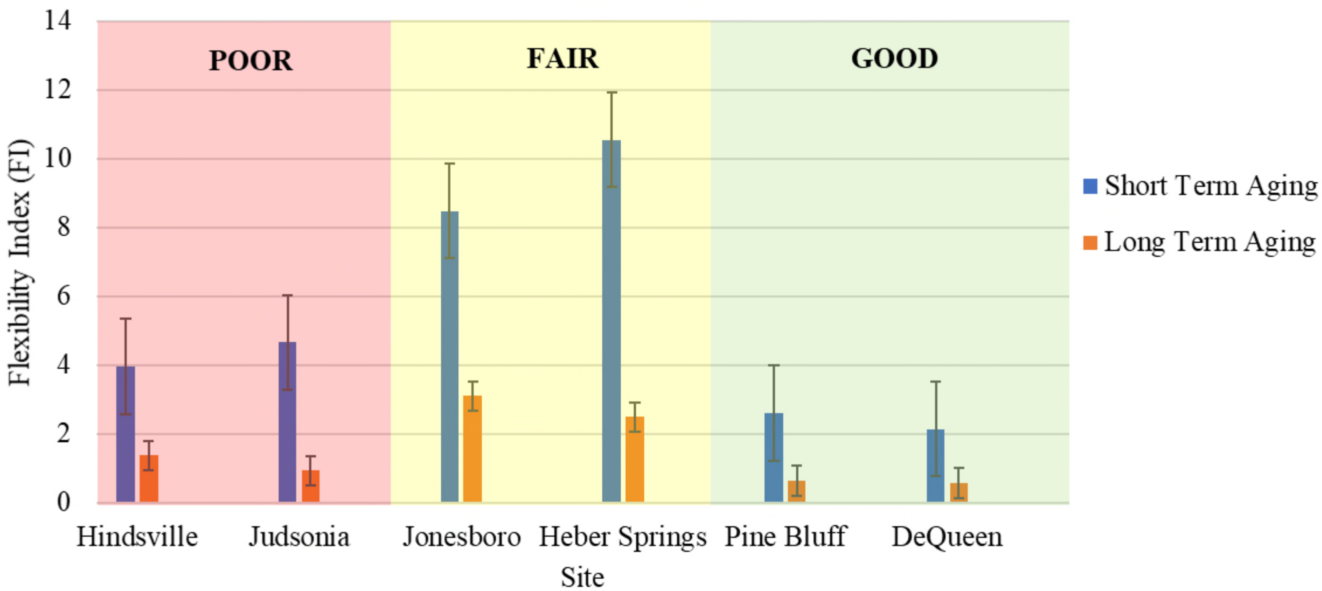


Figure 9. Flexibility Index for each site

Although the results for the good performing sites are not higher than the fair or poor sites they do appear to group together with the FI average for each site only differing by 0.47 for short term oven aging and 0.07 for the long term oven aging. One theory for the good performing field results having poor performing lab results has to do with the peak load achieved on the specimens for those sites. Table 3 is a compilation of the peak load averages for each site and aging protocol.

Table 5. Peak Load Averages

Poor	**Hindsville**	**Judsonia**
Short Term Aging	3.00	3.24
Long Term Aging	4.00	4.85
Fair	**Jonesboro**	**Heber Springs**
Short Term Aging	2.74	2.62
Long Term Aging	3.75	3.97
Good	**Pine Bluff**	**DeQueen**
Short Term Aging	3.26	3.95
Long Term Aging	4.46	4.91

The two good perfoming field sites (Pine Bluff and DeQueen) have high peak loads- 3.26 and 3.95, respectively, for short term and 4.46 and 4.91, respectively, for long term. It is possible that the sites appear good performing because they have yet to reach their peak load in the field. I-FIT only measures crack propogation, not crack initiation. The specimens created in the labe are in a sense pre-cracked because of the saw cut notch. If the good sites in the field had experienced crack initiation they may not be ranked as good.

T-statistics and F-statistics were completed on the I-FIT FI data. Table 6, 7, and 8 are an illustration of the T-test results. Tables 9, 10, and 11 are an illustration of the F-tests results. There is a higher variability among the short term aging sites. The short term aging sites also have higher FI values. There is a difference in mean between Poor, Fair, and Good Sites for both short term and long term oven aging.

Table 6. T-Test Summary

	Within Site	**mean**	**t-stat**	**t-crit**	**Significant**
Poor R30	Hindsville	3.96	1.35	2.08	NO
	Judsonia	4.66			
Poor NCAT	Hindsville	1.38	2.72	2.16	YES
	Judsonia	0.94			
Fair R30	Jonesboro	8.48	2.23	2.08	YES
	Heber Springs	10.55			
Fair NCAT	Jonesboro	3.11	1.69	2.08	NO
	Heber Springs	2.49			
Good R30	Pine Bluff	2.61	1.45	2.07	NO
	DeQueen	2.22			
Good NCAT	Pine Bluff	0.64	0.75	2.09	NO
	DeQueen	0.57			

Table 7. T-Test Summary (Between Sites)

	Between Sites	mean	t-stat	t-crit	Significant
Poor vs. Fair (R30)	Poor Fair	4.31 9.52	9.18	2.03	YES
Poor vs. Fair (NCAT)	Poor Fair	1.16 2.8	7.78	2.03	YES
Fair vs. Good (R30)	Fair Good	9.52 2.42	13.61	2.06	YES
Fair vs. Good (NCAT)	Fair Good	2.8 0.6	11.24	2.06	YES
Good vs. Poor (R30)	Good Poor	2.42 4.31	6.36	2.03	YES
Good vs. Poor (NCAT)	Good Poor	0.6 1.16	5.54	2.03	YES

Table 8. T-Test Summary (Aging Protocols)

Site	Aging Protocol	mean	t-stat	t-crit	Significant
Hindsville	R30 NCAT	3.96 1.38	7.23	2.12	YES
Judsonia	R30 NCAT	4.66 0.95	9.12	2.2	YES
Jonesboro	R30 NCAT	8.48 3.11	6.85	2.14	YES
Heber Springs	R30 NCAT	10.55 2.49	13.02	2.14	YES
Pine Bluff	R30 NCAT	2.61 0.63	9.44	2.18	YES
DeQueen	R30 NCAT	2.22 0.57	8.71	2.13	YES

Table 9. F-Test Summary

	Within Site	variance	F	F-crit	Significant
Poor R30	Hindsville	1.25	1.83	4.3	NO
	Judsonia	1.96			
Poor NCAT	Hindsville	0.29	7.4	4.3	YES
	Judsonia	0.02			
Fair R30	Jonesboro	6.39	4.97	4.3	YES
	Heber Springs	3.97			
Fair NCAT	Jonesboro	0.99	2.86	4.3	NO
	Heber Springs	0.63			
Good R30	Pine Bluff	0.5	2.11	4.3	NO
	DeQueen	0.37			
Good NCAT	Pine Bluff	0.03	0.57	4.3	NO
	DeQueen	0.06			

Table 10. F-Test Summary (Between Sites)

	Between Sites	variance	F	F-crit	Significant
Poor vs. Fair	Poor	1.66	84.22	4.05	YES
(R30)	Fair	6.07			
Poor vs. Fair	Poor	0.2	60.6	4.05	YES
(NCAT)	Fair	2.8			
Fair vs. Good	Fair	6.07	185.26	4.05	YES
(R30)	Good	0.45			
Fair vs. Good	Fair	0.87	126.36	4.05	YES
(NCAT)	Good	0.05			
Good vs. Poor	Good	0.45	40.49	4.05	YES
(R30)	Poor	1.66			
Good vs. Poor	Good	0.05	30.67	4.05	YES
(NCAT)	Poor	0.2			

Table 11. F-Test Summary (Aging Protocols)

Site	Aging Protocol	variance	F	F-crit	Significant
Hindsville	R30	1.24	52.21	4.3	YES
	NCAT	0.29			
Judsonia	R30	1.96	83.57	4.3	YES
	NCAT	0.02			
Jonesboro	R30	6.39	46.92	4.3	YES
	NCAT	0.99			
Heber Springs	R30	3.97	169.49	4.3	YES
	NCAT	0.63			
Pine Bluff	R30	0.5	89.18	4.3	YES
	NCAT	0.03			
DeQueen	R30	0.37	75.91	4.3	YES
	NCAT	0.06			

The results from this research compare to results from research conducted in other states. A study from NCAT tested 7 different mixtures with FI values ranging between 0.4 and 10.4 (Moore 2016). A study from Missouri analyzed field cores of Superpave mixtures and FI values ranged from 0.14 to 4.98 (Butler et al. 2018). The long term oven aging results from this study are similar to those values ranging between 0.57 and 3.11.

Conclusion

It was the goal of this research to determine if I-FIT could be implemented in the State of Arkansas to characterize cracking susceptibility of an asphalt concrete mixture during the mixture design process. If I-FIT is implemented in Arkansas it is important to note that the FI value is an index and not a predictor. The FI should not be used as factual but as an estimator of how an asphalt mixture might perform. The results of this study can be summarized as follows:

- The short-term oven aging specimens yielded higher FI's than their long-term oven aging counterparts.
- FI averages for both short-term and long-term oven aging for each site appear to appropriately group the results.

- The laboratory results of the poor and fair sites corresponded with the field performance of those sites.
- The laboratory results of the good performing sites did not correlate with the field performance of the two good performing sites analyzed.
- The good performing sites had higher peak loads than most of the other sites tested.
- There is a higher variability among FI results as the FI value increases.
- There is a statistical difference between the Poor, Fair, and Good sites lab results for both short term and long term oven aging.

If only the poor and fair performing sites were analyzed I-FIT would be a good choice for Arkansas. The field and laboratory performances seem to correlate for both the poor and fair performing sites. To extend that correlation to the good performing sites more research would need to be completed. This research should attempt analyze more Good field performing sites in the state of Arkansas to determine if these results of the good sites are anomalous.

Recommendations

From the statistical analysis both short term (AASHTO R30) and long term (NCAT) oven aging could be used to discriminate between I-FIT results. Given that short term oven aging results were statistically different among the sites it is recommended that short term oven aging be used rather than long term oven aging due to the shorter time it takes to complete. The state of Illinois uses an FI minimum value of 8 using short term aging as a base value of mixture acceptance. After analysis of the data of FI values for this research it would be recommended to use a FI value of 5 for acceptance when using short term oven aging. A value of 5 is a conservative value, but it is higher than the highest FI value in poor category of this research.

This value could be amended as more research is conducted. However, this conservative value would currently allow more mixtures to pass the cracking criteria.

References

AASHTO. (2015). “Standard practice for mixture conditioning of hot mix asphalt (HMA).” R 30-02, Washington, D. C.

AASHTO. (2016). “Standard method of test for determining the fracture potential of asphalt mixtures using semicircular bend geometry (SCB) at intermediate temperature.” TP 124-16, Washington, D. C.

AASHTO. (2016). “Standard method of test for theoretical maximum specific gravity (Gmm) and density of hot mix asphalt (HMA).” T 209-12, Washington, D. C.

AASHTO. (2017). “Standard method of test for specific gravity and absorption of fine aggregate.” T 84-13, Washington, D. C.

AASHTO. (2017). “Standard method of test for bulk specific gravity (Gmb) and density of compacted asphalt mixtures using automatic vacuum sealing method.” T 331-13, Washington, D. C.

AASHTO. (2017). “Standard method of test for specific gravity and absorption of coarse aggregate.” T 85-14, Washington, D. C.

AASHTO. (2017) “Standard specification for Superpave volumetric mix design.” M 323-17, Washington, D. C.

AASHTO. (2017). “Standard practice for Superpave volumetric design for asphalt mixtures.” R 35-17, Washington, D. C.

AASHTO. (2017). “Standard Specification for Performance-Graded Asphalt Binder.” M 320-17, Washington, D. C.

Al-Qadi, I. L., H. Ozer, J. Lambros, A. El Khatib, P. Singhvi, T. Khan, J. Rivera-Perez, and B. Doll. (2015). Testing protocols to ensure performance of high asphalt binder replacement mixes using RAP and RAS. Illinois Center for Transportation, Illinois Department of Transportation

ARDOT. (2019). “Test method for determining rutting susceptibility using a loaded wheel tester (LWT).” 480-07, Little Rock, AR

Bazant, Z. P. (1996). “Analyzis of work-of-fracture method for measuring fracture energy of concrete.” Journal of Engineering Mechanincs, Vol. 122, No.2, pp. 138-144.

Braham, Andrew., Underwood, Shane B. (2016). “State of the art and practice in fatigue cracking evaluation of asphalt concrete pavements.” Version 1.0

Butler, William G., Meister, Jim., Jahangiri, Behnam., Majidifard, Hamed., (2018). “Performance Characteristics of Modern Recycled Asphalt Mixes in Missouri, Including Ground

Tire Rubber, Recycled Roofing Shingles, and Rejuvenators." University of Missouri-Columbia, Missouri Department of Transportation.

Chen, Chen., Yin, Fan., Turner, Pamela., West, Randy, C., Tran, Nam., (2018). "Selecting a laboratory loose mix aging protocol for the NCAT top-down cracking experiment.

Goad, Stacy Denise. (1998). Superpave Mixture Design Implementation in Arkansas. Masters thesis. University of Arkansas, Fayetteville

Hall, Kevin D., Braham, Andrew F. (2017). "TRC1802 Performance-based asphalt mixture design (PBD) for Arkansas." Department of Civil Engineering, University of Arkansas, Fayetteville

Hall, Kevin D., Castillo-Camarena, Elvis A., Parnell, Nathan. (2019). "Effects of Aging Protocols of a Cracking Test in Asphalt Mixtures." Department of Civil Engineering, University of Arkansas, Fayetteville

Hillerborg, A. (1985). "The theoretical basis of a method to determine the fracture energy of concrete." Materials and Structures, Vol 18, No.4, pp. 291-296.

McCarthy, L. M., J. Callans, R. Quigley, and S. V. Scott, III (2016). "Performance Specifications for asphalt mixtures." National Cooperative Highway Research Program, Synthesis No. 492., Washington, D. C.

Moore, Nathan D., (2016). "Evaluation of Laboratory Cracking Tests Related to Top-Down Cracking in Asphalt Pavements." Masters Thesis. Auburn University

Ozer, H., Al-Qadi, I. L., Lambros, J., El-Khatib, A., Singhvi, P., and Doll, B. (2016a). "Development of fracture-based flexibility index for asphalt concrete cracking potential using modified semi-circular bending test parameters." Construction and Building Materials, 115, 390-401

Ozer, Hasan. Al-Qadi, I. L. (2018). "Development and implementation of the Illinois Flexibility Index Test: A protocol to evaluate the cracking resistance of asphalt mixtures." Transportation Research Circular, (E-C237)

Richey, Allyson. (2017). "Using historic pavement performance data to identify and select sites for asphalt mixture design studies." Honors thesis. University of Arkansas, Fayetteville

Zhou, F., Newcomb, D., Gurganus, C., Banihashemrad, S., Park, E., Sakhaeifar, M., Lytton, R. (2016). "Experimental design for field validation of laboratory tests to assess cracking resistance of asphalt mixtures." National Cooperative Highway Research Program, NCHRP 9-57., Washington, D. C.